ANL VTO ANALYSIS MODELING PROGRAM

Project ID: VAN017

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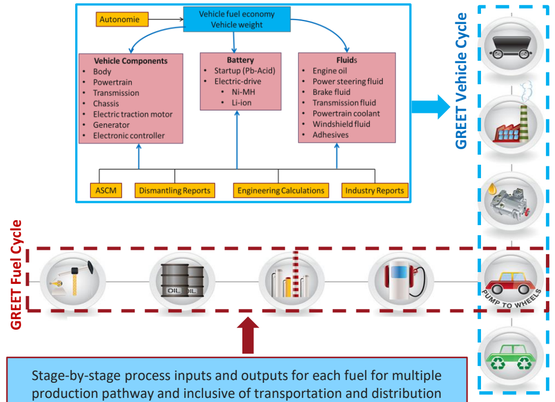
RELEVANCE: PROJECT OVERVIEW

- Overcome inconsistent data, assumptions, and guidelines by developing transparent models
  - **GREET®** life-cycle analysis (LCA) model: Holistically addresses energy and environmental impacts of vehicle/fuel systems
- To develop indicators and methodology for environmental sustainability and to evaluate energy and emission benefits of vehicle/fuel systems, GREET includes:
  - Energy use by different technologies
  - Greenhouse gas (GHG) emission impacts for climate change effects
  - Air pollutant emission impacts (NO_x, PM_{10}, SO_x, VOC, etc.) and regional impacts
  - Water consumption for interactive effects of water-energy nexus

RELEVANCE: TASK OBJECTIVES

- ***Task 1:*** Model vehicle cycle for medium-duty (MD) trucks (Class 6 box) and heavy-duty (HD) trucks (Class 8 long-haul and regional) and integrate into the GREET model for energy and environmental evaluation
- ***Task 2:*** Develop monthly, sectoral consumption-based regional electricity characteristics and conduct WTW analysis of selected BEVs
- **Task 3:** Perform integrated system assessment of vehicle/fuel systems to develop cradle-to-grave (C2G) GHG emissions for small SUVs and well-to-wheels (WTW) GHG emissions for M/HDV
- ***Task 4:*** Develop GREET model and provide EERE/VTO support

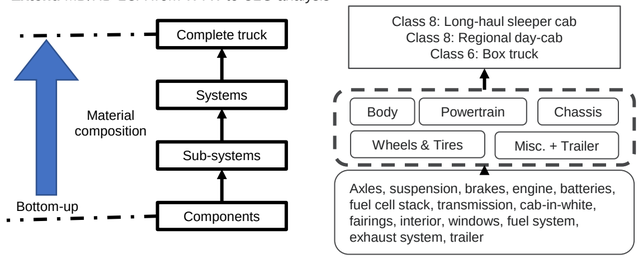
SYSTEMS APPROACH TO LCA

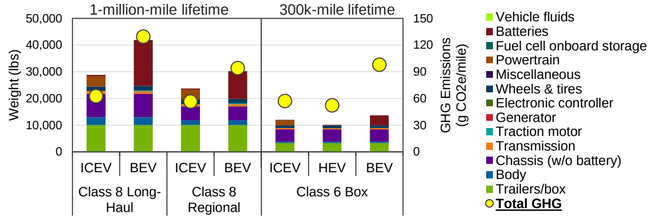


Stage-by-stage process inputs and outputs for each fuel for multiple production pathway and inclusive of transportation and distribution (pipelines and/or shipping).

TASK 1 APPROACH & RESULTS: MD/HD VEHICLE CYCLE ANALYSIS

- **Expand** GREET life-cycle analysis scope of MD/HD vehicles from WTW to C2G
- **Include** conventional diesel, hybrid electric, and battery electric vehicles
- **Identify** MD/HDV component weights and material compositions
- **Milestone – On-Schedule:** Integrate mass and material compositions into GREET2 for MD/HDV vehicle cycle analysis
- **Extend** MD/HD LCA from WTW to C2G analysis





M/HDV material compositions and GHG emissions vary by powertrain type and assumed mileage.

TASK 2 APPROACH & RESULTS: CONSUMPTION-BASED ELECTRICITY

- Develop network-based modeling framework for North American grid (**Milestone – Complete**)
  - Collect and process monthly fuel consumption, electricity generation, interchange, sales, and GHG emissions and air pollutants for 2017
  - Use GREET.net to derive consumption-based electricity mixes, energy/emission intensities at monthly and regional grid level

Differences (Consumption – Generation)

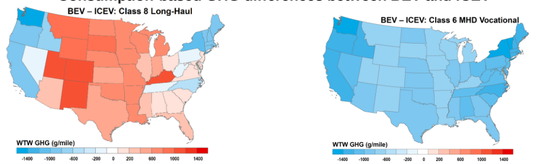
	Jan.											Dec.
Other	-0.5%	-0.1%	-0.5%	-0.4%	-0.4%	-0.3%	-0.3%	-0.3%	-0.3%	-0.4%	-0.6%	-0.4%
Geo	-0.8%	-0.9%	-0.8%	-0.8%	-0.7%	-0.6%	-0.7%	-0.6%	-0.7%	-0.6%	-0.7%	-0.8%
Wind	-1.0%	-1.0%	-0.9%	-1.2%	-2.1%	-1.4%	-0.8%	-1.1%	-1.1%	-0.3%	-0.1%	-0.1%
Solar	-1.5%	-2.2%	-3.4%	-3.9%	-4.2%	-3.8%	-3.1%	-2.3%	-3.2%	-3.3%	-2.6%	-3.0%
Hydro	1.0%	2.9%	3.4%	5.8%	6.0%	6.2%	2.9%	1.4%	3.0%	2.8%	2.7%	4.5%
Nuclear	0.9%	0.8%	1.1%	-0.3%	0.8%	0.6%	0.4%	0.7%	0.5%	-0.1%	-0.1%	0.1%
Biomass	-0.2%	-0.2%	-0.3%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.3%	-0.4%
Oil	0.1%	0.0%	0.0%	0.1%	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%
Gas	-6.0%	-6.3%	-3.3%	-2.0%	-3.0%	-4.0%	-3.2%	-3.0%	-4.0%	-5.1%	-7.4%	-7.8%
Coal	8.0%	7.1%	4.7%	3.0%	3.8%	3.5%	4.8%	5.3%	5.9%	7.1%	9.1%	7.9%

Monthly percentage point difference between generation and consumption mixes for the CA Independent System Operator (2017): implications of imported hydropower from WA & OR) and coal power from AZ & UT. A generation-based approach overlooks imports.

TASK 2 APPROACH & RESULTS: APPLICATION OF CONSUMPTION-BASED MODEL TO SELECT BEV

- Evaluate selected MD/HDVs at state level for ICEV and BEV
  - Expand previous national analysis to state level with consumption-based regional electricity characteristics in 2017
  - Apply GREET for WTW GHG and air pollutant emissions
  - Include Class 8 long-haul combination, short-haul combination, refuse; Class 6 medium heavy-duty vocational, Class 4 light heavy-duty vocational, Class 2 pickup trucks and vans
  - Use Autonomie model for fuel economy of individual truck technologies

Consumption-based GHG differences between BEV and ICEV



From a consumption-based electricity perspective in 2017, Class 8 long-haul BEVs emit more WTW GHGs than their ICEV counterpart in 27 states, while Class 6 BEVs emit fewer than ICEV in all states.

TASK 3 APPROACH: C2G GHG AND COST FOR LDV

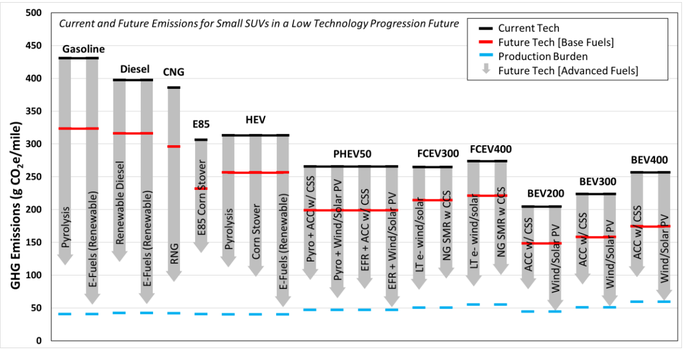
- Model and analyze current and future C2G GHG emissions and costs of midsize cars and small SUVs for US DRIVE ISATT
  - Years: CURRENT – 2020, FUTURE – 2030-2035
  - Utilize Argonne's Autonomie simulation outputs for vehicle characteristics and costs using DOE parameters
  - Apply GREET to develop C2G GHG emissions for vehicle/fuel systems
  - Use DOE models and open literature to identify fuel costs
- **Milestone – On-Schedule:** Conduct LDV C2G analysis & prepare report

Vehicle Technology	Gasoline*	Diesel	CNG	E-fuels	E85	H_2	Electricity
ICEV	X	X	X	X	X		
HEV	X						
H_2 FCEV (300, 400 mi)						X	
BEV (200, 300, 400 mi)							X
PHEV50 ¥	30%						70%

** Gasoline (E10) assumed to contain 10% corn ethanol by volume.*
¥ PHEV gasoline and electricity energy usage mix assumed per SAE J2841.

	CURRENT TECHNOLOGY	FUTURE TECHNOLOGY
Gasoline (E10)	U.S. average crude mix (w/ 10% corn ethanol)	Bio-renewable gasoline (pyrolysis)
Diesel	U.S. average crude mix	Bio-renewable diesel (pyrolysis)
		20% fatty acid methyl ester (soybeans)
CNG	U.S. average (conv./shale mix)	Renewable NG
E-fuels	---	Renewable/low-carbon electricity + waste CO_2
Ethanol (E85)	85% corn ethanol (w/ 15% petroleum gasoline)	85% cellulosic from corn stover (w/ 15% petroleum gasoline)
Hydrogen	Centralized production from NG Steam Methane Reforming (SMR)	Low temp. electrolysis from wind/solar
		High temp. electrolysis from nuclear
		NG SMR with Carbon Capture and Storage (CCS)
Electricity	EIA-AEO U.S. average electricity generation mix in 2020	NG Advanced Combined Cycle (ACC)
		NG ACC with CCS
		Wind power
		Solar photovoltaic (PV)

TASK 3 RESULTS: C2G GHG AND COST FOR LIGHT DUTY VEHICLES



Preliminary C2G results show pathways for deep decarbonization in the future, especially those with low-carbon fuels coupled with efficient powertrains.

TASK 4 APPROACH & RESULTS: C2G & WTW RECORDS FOR EERE

- Utilized GREET for multiple vehicle/fuel systems (informed by latest DOE parameters) to evaluate WTW GHG emissions for gasoline, diesel, E85, electricity, and hydrogen given current (2020) and future (2050) conditions, with future fuel pathways considering deep decarbonization approaches
- Evaluated vehicle cycle effects associated with small SUV production to extend the WTW (fuel) analysis to C2G analysis
- Based vehicle characteristics on latest Autonomie vehicle simulation using DOE parameters
- **Milestone – Complete**: Developed EERE Program Record for C2G GHG emissions of small SUVs for multiple powertrains (ICEV, HEV, PHEV, BEV, FCEV) and years (2020 and 2050)
- Conducted WTW GHG analysis of M/HDVs across multiple vehicle platforms and multiple fueling pathways to understand current and future GHG emissions associated with relevant combinations of each
- **Milestone – On-Schedule**: Develop EERE Program Record for WTW GHG emissions of MD/HDV for multiple powertrains (ICEV, HEV, PHEV, BEV, FCEV) and years (2020 and 2050)

SUMMARY AND PROPOSED FUTURE RESEARCH

- Project objective is to develop modeling capabilities for VTO Analysis Program to estimate energy and environmental effects of vehicle/fuel systems
- Modeled and evaluated vehicle cycle of MD/HDV, C2G GHGs and costs of LDV, and emission effects of consumption-based electricity grid (with application to MD/HDV performance)
- Partnered with key organizations including US DRIVE, OEMs, energy companies, national labs
- **Potential Future Work** (*Any proposed future work is subject to change based on funding levels*)
  - Conduct C2G GHG emissions analysis of MD/HDV
  - Develop emissions considering three scopes (as defined by the UN and industry) for key fuel production pathways in GREET.net
  - Quantify and update environmental metric outputs of the PEV critical materials supply chain
  - Develop country-level air emissions inventories associated with key energy production facility types for use in environmental justice assessment
  - Develop monthly consumption-based electricity results at the state level

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